Real time seawater observation network for aquaculture

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Abstract*—We propose the construction of a seawater temperature observation network that utilizes many compact "ubiquitous buoys" to measure water temperature at different locations and depths. Seawater temperature is an important consideration when determining a suitable timing for various aquacultural operations up to and including shipping products to market. Conventionally, fishermen have used satellite-based and hull-mounted sensing technologies to determine water temperature and its distribution, information which they combine with experience and intuition to schedule their operations. One limitation of this approach, however, is that it cannot be confidently applied to the determination of the seawater temperature distribution below the surface (as it varies with, for example, the movement of water masses). There is thus a strong interest in compact, inexpensive seawater observation buoys that can monitor underwater temperature distributions in real time. In 2004, we began to develop such devices, which we call "ubiquitous buoys." More than 100 such buoys have been installed to date within aquacultural installations and other areas along the Japanese coast; the buoys are used to provide fishermen and other operators with data on seawater temperature at various depths. We are currently working to construct a seawater observation network consisting of densely placed buoys and thereby capable of determining three-dimensional seawater temperature distributions. If this network proves successful in measuring, for instance, the speed and direction of currents or the size of water masses, it should become possible to predict changes in temperature distributions. In this report, we introduce a 20-buoy seawater observation network currently under construction within the Tsugaru Strait, off the southern coast of Hokkaido, Japan.

Keywords-component; Seawater temperature; Aquaculture; Buoy; Observation network; Embedded component

I. INTRODUCTION

The summer of 2010 was characterized by unusually high seawater temperatures along the coast of Hokkaido, the furthest north of the major Japanese islands. This phenomenon had a strongly adverse effect on the coastal fishing industry, as manifested by poor catches of Pacific saury and die-offs of scallop.

Although catches of flatfish (flounder) and flying squid remained at the level of a typical year, a little known fact is that very few live flatfish and flying squid were successfully delivered to market. The weather that summer was marked by high-pressure systems that remained stationary over Hokkaido for extended periods, thereby preventing low-pressure systems from coming in and stirring up the surrounding seawater. This led to stratification—the water on the surface became progressively hotter while deeper water remained cold, such that the temperature differential between the two eventually exceeded 10 °C. Flatfish (a bottom dweller) and flying squid (a deepwater species that travels in schools) would quickly die when brought from such depths and placed in shipboard tanks. Very few survived long enough to be delivered to market.

Many fishermen initially concluded that the fish died because of the high sea surface temperature, in which case there would be little they could do about it. However, upon studying data provided by ubiquitous buoys, a few operators arrived at a different conclusion—the fish died not because of the high surface water temperature, but rather because of the large differential between the surface and bottom temperatures. This led those fishermen to try filling their shipboard tanks with cold water from deep below the surface, an approach that proved successful in allowing them to deliver live catches to market. This case is one example of how temperature data from ubiquitous buoys can be of practical use to coastal fishermen.

The damage wreaked on coastal fisheries in 2010 by the unusually high seawater temperatures underscored the importance of temperature data for coastal fishing and induced a number of fishery cooperatives to introduce ubiquitous buoys. There are eight fisheries cooperatives in the southern portion of Hokkaido, where our university is located. One of the cooperatives already had three ubiquitous buoys in operation, which were installed in 2007 to assist in scallop farming. Then, in 2010, another cooperative also installed three ubiquitous buoys to aid in set netting. Next, in 2011, the remaining six cooperatives installed one to three buoys each in support of kelp farming, squid jigging, and tuna fishing. We are currently working to configure a seawater observation network in southern Hokkaido consisting of 20 ubiquitous buoys and hope to have the network in place by autumn 2011. As shown in Figure 1, the Oyashio Current and Tsushima Current run up against each other in this region. Although this confluence produces excellent fishing grounds, it also leads to complex fluctuations in temperature profiles; in this regard, much is

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expected of the three-dimensional temperature visualization capabilities of our seawater observation network.

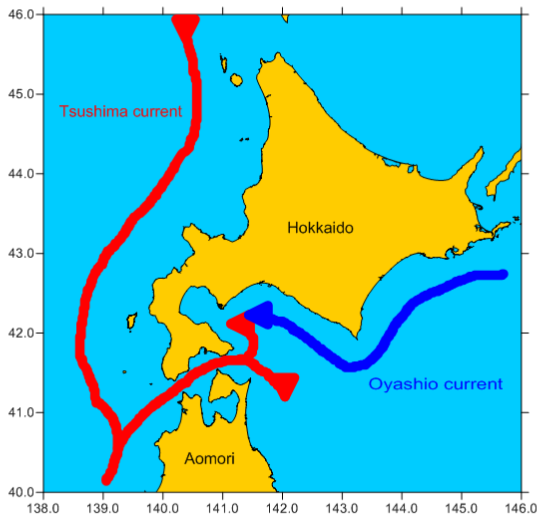

Figure 1. Flow of major currents around southern Hokkaido

II. Ubiquitous Buoy

A. Ubiquitous buoy: an overview

We began developing ubiquitous buoys in 2004 as a tool to assist coastal fishermen (1) (2). Of the various regions of Japan, the aquacultural industry is most active in the northern prefecture of Hokkaido, which accounts for approximately half of Japanese fisheries production. The primary forms of coastal fishing in this region are scallop farming, kelp farming, and salmon set netting. As both farming and set netting are stationary in nature, it becomes necessary to operate in a manner that accords with the characteristics of the immediate environment (the fishing grounds), and of course seawater temperature is one of the most important of those characteristics. Scallop, for instance, lose their strength when exposed to rapid changes in seawater temperature, and thus "ear hanging" (explained in more detail later) must be carried out when the temperature is stable. Kelp is known to come under parasitic attack when the temperature of the surrounding water exceeds 17 °C. And salmon do not start schooling along the coast—and thus do not enter the set nets placed along it—until the temperature of the bottom water layers falls below 20 °C. Reflecting the significance of seawater temperature for coastal fishermen, efforts have been made to monitor it at multiple levels (depths) using thermometer recorders, most typically with Tidbit underwater temperature data loggers (3). Problems here, however, include that such devices generally record data over one-month intervals, at least, and that the data collected at the end of that period is historical, not real-time, and thus of only limited utility. Furthermore, conventional oceanographic buoys are expensive, well out of the reach of sole-proprietor fishermen, and bulky, such that they do not applicable in many of the places. For these reasons, there has been much interest in the development of compact, inexpensive buoys capable of measuring seawater temperature in real time. We set out to develop such a device by bringing together sensor networking and embedded components.

Our efforts also included the development of a water temperature sensor specifically for this application. This sensor features a multidrop connection, an arrangement that allows multiple sensors to be linked with a single cable. One unit is structurally capable of measuring water temperature at up to 16 levels, although so far measurements have been taken up to only 10 levels. Measurement data is transmitted from the buoy to a server in an e-mail format via a cellular link.

The greatest single technological obstacle encountered in the buoy development process was the need to minimize energy consumption. By implementing a sleep function, we were able to reduce energy requirements to the point where four D-size alkaline batteries proved sufficient to continuously operate a buoy over an 18-month period. We also found that a buoy could also be kept in continuous operation with a combination of a solar panel and an electric double-layer capacitor arrangement.

The first generation of ubiquitous buoys was utilized primarily for testing and assessment. Second- and-third-generation buoys, however, were produced in quantity, with over 100 such buoys placed within aquacultural facilities along the Japanese coast. A fourth-generation of buoys, completed in March 2011, features an international roaming capability. This newest type of buoy is described in more detail in Section IV.

B. Fourth-generation ubiquitous buoys: specifications

A fourth-generation ubiquitous buoy comprises one control board, one battery, and at least one water temperature sensor. Each of these components is contained within its own waterproof case and connected by cable. Figure 2 shows a photograph of a controller and a sensor, and Table 1 lists their specifications. Mounted on the control board is a communications module taken from a cellular phone, and printed onto the board itself is a two-frequency (800 MHz and 2 GHz) non-directional antenna. Although the method of buoy placement varies to a certain extent by region, in most cases it is attached to a fishing marker buoy (pole), as shown in Figure 3.

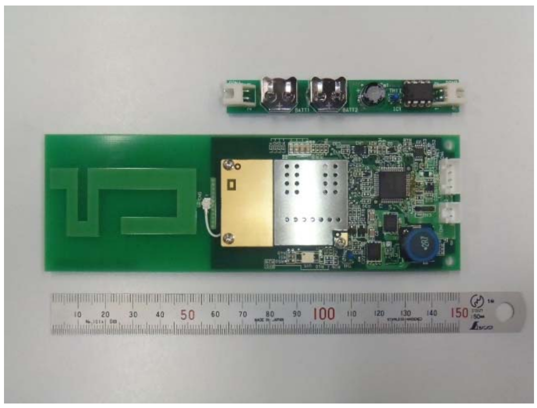

Figure 2. Fourth-generation ubiquitous buoy controller and sensor

TABLE I. SPECIFICATIONS OF CONTROLLER AND SENSORS

	Controller	Sensor
Size	150.0 mm × 49.5 mm	85 mm × 12 mm
Wight	45 g	10 g
CPU	HD64F2212	PIC12F683
Clock	14.746MHz	4MHz
Interface	RS-485 (half-duplex)	RS-485 (half-duplex)
Case size	φ60 mm × 184 mm	φ25 mm × 110 mm
Total wight	420 g	90 g
Thermistor	-	103AP-2
Range	-	-9.9 °C to 40.0 °C
Accuracy	-	±0.2 °C

Figure 3. Standard placement of ubiquitous buoy

III. SEAWATER OBSERVATION

A. Multilevel measurement

A ubiquitous buoy is structurally capable of taking temperature measurements at a maximum of 16 levels. Generally speaking, a sensor is placed at 10-meter intervals when the buoy is to be used in water over 30 meters deep and at 5-meter intervals when the buoy is to be used in shallower water. Figure 4 shows a graph of seawater temperature measurements taken in July 2010 off the west coast of Hokkaido. We note that the temperature of the surface layer was well over 20 °C during that month (mean temperature: 20.9 °C). We also note that the temperature differential between the surface layer and the lowest layer sometimes exceeded 10 °C. Along the Hokkaido coast, it is rare for monthly average surface temperature to exceed 20 °C—thus we concluded that the seawater was unusually hot in this season. Figure 5 shows a graph of water temperature within the same region in July 2009 which supports this conclusion. Relative to Figure 4, we note that the temperature of the surface layer is low and that the temperature of the bottom layer is high. The temperature differential is thus comparatively small. Unexpectedly, the monthly average temperature at the 30-meter layer was 16.1 °C in 2009 but only 14.2 °C in 2010; that is, it was somewhat lower in 2010, the hotter of the two years. The same tendency is also apparent at the 20-meter layer. However, at the 10- and 0.5-meter layers, the water was warmer in 2010. Interestingly, the average temperature for the four layers comes out to 17.4ºC for 2009 and 17.3ºC for 2010—that is, there was no marked difference in that measure.

From these results, we can conclude that we cannot dependably infer a temperature distribution from just the temperature of the surface layer. That is, for aquacultural facility operators and other coastal fishermen, it is necessary to take measurements at multiple levels—as can be done with a ubiquitous buoy—in order to dependably determine the temperature distribution from the surface downward.

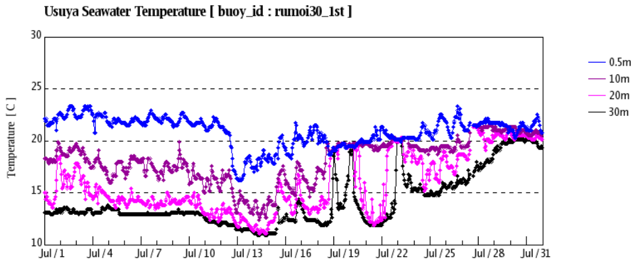

Figure 4. Time course of seawater temperature at various depths: July 2010

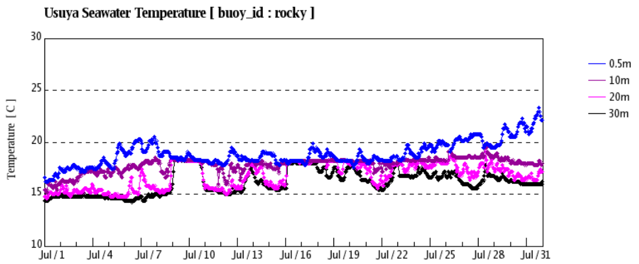

Figure 5. Time course of seawater temperature at various depths: July 2009

B. Multipoint measurement

Partly because of their compactness and low-price, ubiquitous buoys are often placed in pairs or trios. The data obtained from them is made available to the public, thereby enabling concerned fishermen to determine seawater temperatures not only on an absolute basis for a specific point, but also on a relative basis over a general area. Figure 6 shows the placement of ubiquitous buoys off the coast of southern Hokkaido, where they form an observation network. Figure 7 plots seawater temperature measurements taken at Station 31 (off Kinaoshi, Hokkaido) over the first week of July 2011. Station 31, like Stations 27–30, Station 32, and Station 35, is situated at a point exposed to the Oyashio Current. Because of that current, deep-water temperatures remain low at approximately 5 °C even throughout the summer, and thus there is a large temperature differential between the surface and bottom layers. Another characteristic of the area is that the temperature of the surface water can fluctuate markedly within a day (recall that a rapid rise or fall in seawater temperature can produce die-offs at scallop farms). Figure 8, in contrast, plots seawater temperature measurements taken at Station 38 over the same period. Because of located off Yoshiokafukushima, this station, like Stations 33, 34, 36, 37, 39, 40, and 41, is exposed to the Tsushima Current. At Station 38, the bottom layers are relatively warm and, accordingly, temperature differentials are comparatively small.

In this manner, an observation network consisting of multiple measurement points makes it possible to determine three-dimensional temperature distributions and current strength, which in themselves can be applied to the identification of promising sites for, among other operations, squid or tuna fishing.

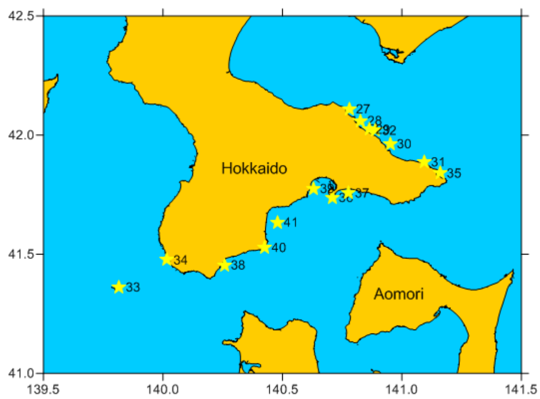

Figure 6. Seawater temperature observation network off southern Hokkaido

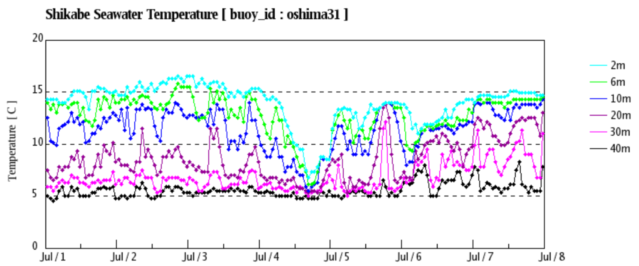

Figure 7. Temperature distribution at Station 31 over first week of July 2011

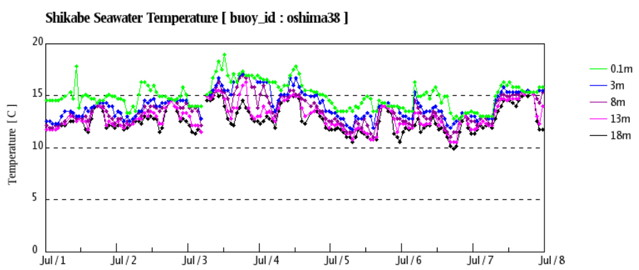

Figure 8. Temperature distribution at Station 38 over first week of July 2011

IV. Development of Ubiquitous Buoy Plus

As ubiquitous buoy installations became increasingly common, we began to field requests from fishermen for buoys that could measure not only seawater temperature, but also current strength and salinity. Ubiquitous buoys utilize the RS-485 standardized communications interface for their connections with seawater thermometers and thus could conceivably accommodate any type of sensor that utilizes that interface. With this in mind, we set about developing a buoy that in addition to seawater thermometers also supports current flow sensors and CTD (conductivity, temperature, and depth) loggers. On a related front, we also took this as an opportunity to develop a self-powering capability through the use of a renewable, environmentally friendly energy source—the sun. These efforts led to what we call the "ubiquitous buoy plus." Below we outline the features of three types now under assessment.

A. *Ubiquitous buoy plus: current observation*

Scallop and kelp farmers cannot work at sea when tidal currents are strong, and gill netters similarly find themselves unable to operate under such conditions because of an inability to cast their nets. Usually, the only way to determine whether the currents are too strong is taking a boat out to the fishing grounds and checking. Here, an ability to determine such conditions remotely would do much to increase operational efficiency. Similarly, ready access to both current and three-dimensional temperature data would allow operators to predict temperature changes and schedule their work accordingly.

Figure 9 shows an AEM-DI (JFE Advantech), a current sensor composed of a 2-axis electromagnetic sensor and a built-in Hall-effect compass. The information this unit provides can be synthesized to calculate current data. We have completed the development of two components related to AEM-DI: a communications program for the controller board and a program for the server display (Figure 10). We are now working on a third component: a power supply unit. Once that task is finished (in August 2011 or beyond), we plan to place several units along the southern coast of Hokkaido for testing and assessment.

Figure 9. AEM-DI current sensor

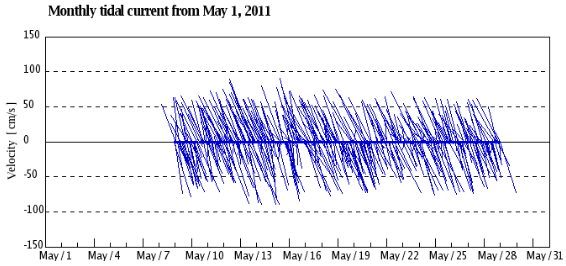

Figure 10. Current measurements over the month of May 2011

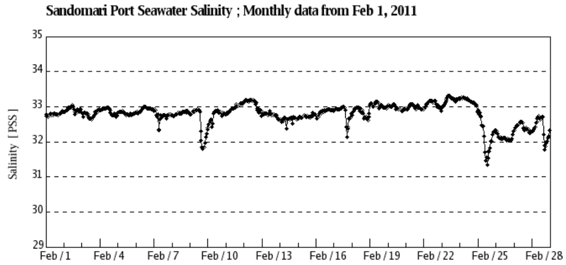

Figure 12. Time course of sea water salinity over February 2011

B. *Ubiquitous buoy plus: salinity observation*

Every year in May off the southern shores of Hokkaido, scallop farmers perform an operation called "ear hanging"—they drill a small hole through the "ear" of each scallop and, by running a fishing line through the holes, bundle them for suspension in the water. The process is physiologically stressful for the scallops; if done while they are not in good condition, a massive die-off can result. May also happens to be the month in which snowmelt from neighboring mountains flows down the rivers of Hokkaido into the sea, decreasing its salinity. Because low-salinity water is also physiologically stressful for scallops and weakens them, exposure to such water masses raises the risk of a die-off following the ear hanging process. Here, a fisherman with a real-time grasp of local seawater salinity would be able to schedule the process to avoid times of particularly high vulnerability (i.e., times of recent exposure to low-salinity water masses) and thereby prevent a die-off.

Figure 11 shows a XR-420 CTD sensor (RBR, Ltd.). Data provided by this sensor—seawater conductivity, temperature, and pressure—can be processed to determine salinity (4). Assessment trials are currently being conducted within fish-farming tanks adjacent to fishing ports. Figure 12 shows a salinity distribution over the month of February 2011.

Figure 11. XR-420 CTD sensor

C. *Ubiquitous buoy plus: solar panel*

Following the trend toward clean energy utilization, we also worked to provide the ubiquitous buoy plus with self-powering capability. Largely because of their energy efficiency, ubiquitous buoys were already well suited to operation with renewable energy sources. The primary difficulty, however, was that the rechargeable batteries conventionally necessary for storage have low energy density and thus cannot be miniaturized to a large extent. For this reason, primary (non-rechargeable) batteries, which have high energy density, were used instead.

Recent improvements in semiconductor technology, however, have led to the development of large-capacity electric double-layer capacitors. Because they combine high energy density with low internal resistance, such devices are well suited to operation with solar cells. Figure 13 shows several core components of a self-powered ubiquitous buoy plus, specifically a 0.5 W solar panel, three 2.5 V, 250 F electric double-layer capacitors, and a second-generation controller board.

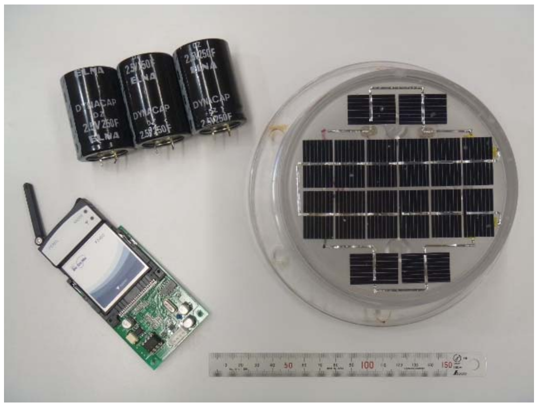

Figure 13. Ubiquitous buoy plus: main components, including solar panel

Several prototype units are now under evaluation off Okinawa, southern Japan, where sunlight conditions are particularly favorable (Figure 14). Figure 15 shows a graph of the output voltage of an electric double-layer capacitor arrangement over the month of February 2011. We note a daily cycling where the voltage begins to increase at about 7 am and peaks around 3 pm. Because the internal resistance of the unit is low, there is little difference in the cycling pattern from one day to the next day, even though some days may be sunny and others cloudy. We plan to next conduct assessments off Hokkaido and begin to produce self-powered units in volume by the end of 2013.

Figure 14. Ubiquitous buoy plus: evaluation of solar-powered unit

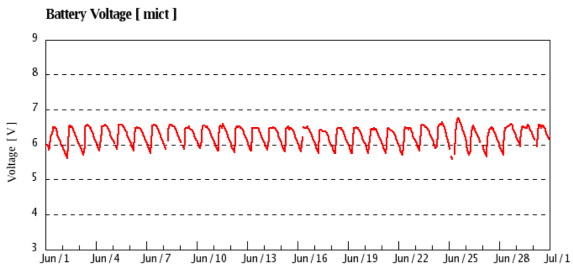

Figure 15. Voltage output over the month of February 2011

V. CONCLUSION

Discussed within this report are the configuration of a seawater observation network utilizing ubiquitous buoys developed by the authors and the recent developments relating to the ubiquitous buoy plus. Believing real-time seawater temperature data to be indispensable in improving the productivity and efficiency of aquacultural facilities and other coastal fishing operations, we have continually worked to develop and refine compact, inexpensive ubiquitous buoys for such applications. Fishing cooperatives and aquacultural research organizations have been picking up the pace of ubiquitous buoy installation, in 2010 in particular, a year in which unusually high water temperatures underscored the importance of real-time access to seawater temperature data. Compactness is another factor that promoted the utilization of ubiquitous buoys by sole-proprietor fishermen in particular—the buoys can be easily carried by a single person and installed without difficulty in fish-farming enclosures by simply lowering them from an outboard boat.

In increasing numbers, such buoys constitute a network, within which seawater temperature information propagates from isolated points to form a continuous plane and, from there, gradually unfolds into spatial and temporal dimensions, steadily gaining value as it does.

In May 2011, we began to install fourth-generation ubiquitous buoys off the east coast of South Korea (Figure 16). Korea and Japan are both located along the Sea of Japan, and by sharing data gathered along the Korean coast, we should become able to better monitor the effect of the Tsushima Current, which flows into the Sea of Japan from the East China Sea. We are eager to place ubiquitous buoys in as many locations as possible, both at Japan and abroad; we hope to promote the active utilization of information obtained from these buoys in support of aquacultural operators and other coastal fishermen.

Real-time seawater temperature data obtained from our ubiquitous buoy network are publicly available on the Internet and can be accessed at our homepage (http://buoy.jp).

Figure 16. Fourth-generation ubiquitous buoy placed off South Korea

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